TOWARDS THE DEVELOPMENT OF A NITROGEN DECISION SUPPORT SYSTEM FOR RADIATA PINE

By

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Introduction

Management of nitrogen fertilisation of radiata pine using foliar N concentrations alone was seen as suboptimal. A more advanced and integrated approach was needed. A project was undertaken by the Forest Site Management Cooperative to evaluate the current methods used for making N fertiliser decisions and to review possible improvements to those methods. As with the development of the Phosphate DSS (Skinner et al 1998 Cooperative report 102), we did not aim to build software, but rather to synthesise knowledge as the foundation for development of tools, whether software based or otherwise.

Current Approach to Nitrogen fertiliser decision making

The current approach is based almost solely around foliar critical levels (eg Will 1985), and we can split predictions of response into two groups:

- If foliar N is less than 0.9% a volume response is to be expected in most cases.
- If foliar N >0.9% then the response is less certain, however it becomes much more certain if the stand is thinned and pruned just prior (maximum of 1 year) to fertilisation. Response can be gained in this latter case almost irrespective of foliar N concentration.

Soil critical levels are far weaker predictors of volume response and only a general indication of the N fertility of a soil can be given from soil tests; relating soil N to productivity has generally given an extremely weak relationship.

Currently, predictions of volume response and the likelihood of obtaining that response that are generated by the Forest Nutrition Laboratory at *Forest Research* are based on papers written by Ian Hunter summarising results from a number of trials nationwide (Hunter ....) The recommendations are based on the best current published knowledge but could probably be improved. Predictions of response at low foliar N and where stands will be thinned or pruned are acceptable, but the recommendations do not adequately address the grey areas of stands with marginal foliar N (1.2-1.5%) that are not thinned and pruned.

Many factors apart from foliar N can affect growth and response, eg climate, soil moisture supply, understorey composition, and these are not yet catered for.

Factors driving Nitrogen responses

Nitrogen is required for development of plant structure and biomass and is mainly used in protein synthesis. A deficiency of N will lower growth rates by reducing leaf area and photosynthetic rate. If N supply rate is increased then the canopy will react to this and build more foliage biomass and hence increase tree growth rates by fixing more carbon. There is also a strong relationship between photosynthetic rate and canopy N concentration. Changes in canopy dynamics are the key to Nitrogen nutrition.

If foliar levels are not critically deficient then the tree can only respond if it builds more crown - ie a greater leaf surface area allows fixation of more carbon. If the stand cannot build more crown then obviously adding more N will not result in a faster growth rate. Factors limiting crown expansion include stocking - if the stand is tightly stocked there may be other limitations such as shading limiting the possibility of building more crown. Crown disease such as cyclaneusma needle cast can also limit crown response by lowering needle retention values. A third factor would be water supply, or the lack of another nutrient. This could either be due to absolute low levels, or to competition by the understorey for limited resources.

So, *foliar N concentration is only likely to be a major component in response prediction in truly deficient stands*, it will be important in other cases but other factors are likely to be as important or more so.

Important issues related to N nutrition

This element differs to phosphate in that we are more likely to change the tree or stand than the site, fertilisation with N often leads to an increase in tree volume rather than an improvement in the overall site quality.
There are issues of quality associated with N fertilisation. High N levels can lead to unwanted heavier branching and there are possible effects on wood density also.

# Possible approaches to improving N fertiliser decisions

There are a number of possible approaches to building an N response model. These can be split into two groups, canopy based and soil based. There are various options within both of these.

Canopy based methods
Ian Hunter produced a canopy based N response model based on canopy mass and N content. The equation is:

$$\Delta PVI = -0.115 + 0.269.canopyN$$

ΔPVI is the increase in periodic volume increment in the 1st year after fertilisation $(m^3.ha.yr^{-1})$, canopy N is the content of N in the canopy in $kg.ha^{-1}$. If this equation is used to produce a surface of response across a range of crown mass from 4 to 12 tonnes. ha^{-1}, and foliar N concentration of 0.8 to 1.7% the response surface can be illustrated as in Figure 1.

Figure 1. Predicted Volume Response Surface based on Crown Mass Model
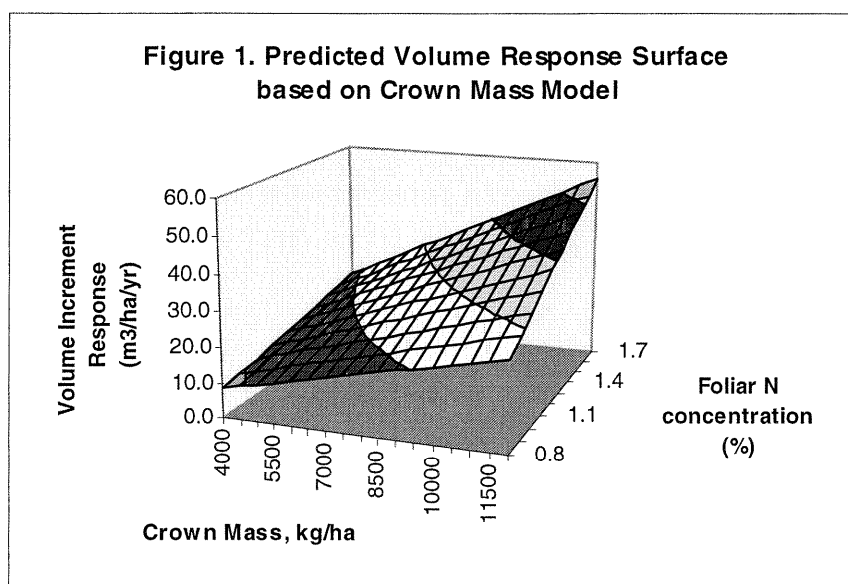
The plot allows the calculation of expected volume increment response if canopy mass was to be changed with a concurrent change in foliar N concentration.

This model is linear and suggests that canopy N concentration has a very strong contribution to the response, which is probably unlikely to be the case except at the very low N concentrations. Some form of non linear response is more likely to apply.
Also at the higher canopy mass it is unlikely that one would find stands with low foliar N concentrations. This model should be further investigated and validated before being used widely.

However, the idea of a crown based model is appealing as there is a very strong relationship between canopy mass and volume growth. The use of other canopy models such as Peter Beets' DRYMAT model may be a useful avenue to explore. This model allows calculation of stem volume growth based on amount of needle mass. Details are given as an appendix to this report in the form of a handout Peter supplied to the NDSS working group for one of the meetings.

There are a number of problems with crown based models however:

1. Should one use leaf area or a measure of crown length? The former is preferable as green crown length does not include a measure of needle retention, which can cause the leaf area to vary widely.
2. How do you measure the leaf area/crown mass accurately? Options here are leaf area meters, calibrated photographs of the canopy, relationships between base of green crown diameter and leaf area, and visual estimates by experienced observers.
3. How accurate do the estimates need to be? A sensitivity analysis of the response model developed would determine this.
4. How does one partition the foliage into different photosynthetic efficiency classes.

These problems are not insurmountable however and research overseas is following the leaf area approach so it may well be feasible. Thinking within Forest Research is tending this way with strong interest in semi process based growth models.

Approach that could be taken:

- Visit stand, estimate canopy mass (possibly by photo images, visual assessment against calibrated photos, or image processing techniques)
- identify sites with health problems likely to limit response
- take foliage samples and determine foliar N concentration
- calculate crown mass/N content
- run Hunter or DRYMAT other model (note - DRYMAT does not need N content) to predict change in volume increment
- rank stands based on responsiveness
- fertilise
- evaluate response post fertilisation and update models

Soil based methods.

These methods will not be as direct as the canopy based ones as the tree effectively integrates the multitude of variables affecting growth at a site, but are useful or necessary if trying to predict growth or likely responses on sites where there are no trees, or where we may be planning to change the N supply characteristics by addition of N through legumes. We noted that total soil N is only a very poor indicator of tree growth, mineralisable N is better and is being investigated in Australia by the CSIRO, soil C:N ratio may also be a driver of an N response/growth model and is easier to measure than mineralisable N. Peter Beets has recently been developing a soil C:N driver within DRYMAT with some success. See appended notes on C:N and on the DRYMAT model.

There are constraints on this approach also:

- type of C and N measured - total values may not be as good as mineralisable values in reflecting actual supply rates
- there will be interactions with other site variables eg soil moisture supply, other nutrient availability
- soil information availability is often limited, though total elemental analysers mean analysis is now cheaper and data easier to obtain.
- Long term data is scarce so little is known about trends in C:N over a rotation.
- May be hard to use in evaluating short term growth responses following N application as C:N ratio may not be permanently affected.

Where to next

- Investigate both canopy and soil based drivers of productivity further
- Test both approaches on existing trials/PSPs where soil data is available
- Test canopy approach on trials where crown data is available or if there are none suitable develop experimentation to evaluate approach.
- Work the biological modelling approach into a broader N focus in PGSF and Coop programme. There are a number of complementary projects in existence - identify where there are or can be synergies. Lupin Replacement Research Group, Oversowing trials, controlled release N trials, Eyrewell N supply work etc. This could be a priority issue for the Coop nutrition theme working group for 1998/99.

Literature cited

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Appendix **Description of DRYMAT: A Model for Simulating Growth and Nutrient Cycling Rates in Radiata Pine Stands**

Description of DRYMAT: A Model for Simulating Growth and Nutrient Cycling Rates in Radiata Pine Stands

P. N. Beets, NZFRI, Private Bag, Rotorua, 15 October, 1997.

Introduction

Model objective: The purpose of DRYMAT is to predict dry matter production of managed plantation forests in relation to nutritional factors.

The dry matter and nutrient content of radiata pine stands is complex to quantify because tree growth and nutrient cycling rates vary with the silvicultural system (eg stocking, pruning, thinning, harvesting, rotation number), site factors (eg climate, soil fertility, soil type, disease), and stand age. The approach that was developed to deal with this complexity is based on:

•Either Permanent Sample Plot data, which provide time series measures of stem total volume which are converted to dry matter production using the partitioning functions in DRYMAT.

•Or site specific input data, which DRYMAT uses to predict leaf area efficiency and hence stand growth and architecture, according to the supplied parameters.

This report summarises the concept underlying the DRYMAT model, explains how this approach is useful, and from an assessment of model limitations maps out possible directions for research.

Modelling concept

DRYMAT is a simplification of a process-based compartment model illustrated in figure 1. The dry matter (and carbon) content of living (needles, branches, stems, reproductive parts, and roots) and non-living tree components and litter (but excluding carbon in the mineral soil) are represented as boxes (compartments), and the inter-compartmental flows as arrows. DRYMAT simulates the oven dry weight of model compartments, on a unit area basis, using a system of conservative flow equations (called state transition equations) which are solved simultaneously (Beets 1982). The process based model shown in figure 1 is too complicated for routine use because the inputs for simulating total photosynthetic production and respiration are generally not available, and are difficult to acquire. However, partitioning of growth to various tree components has been examined, and is not particularly complicated to model.

A key concept underlying the DRYMAT model is that, given current knowledge of growth partitioning, mortality, and decay of tree components, the gain in the dry matter content of the stem can be used to predict dry matter gains of the remaining components. Growth gains by living tree components necessarily sum to total current dry matter production from photosynthesis and respiration. Providing stem volume and wood density data as model inputs serves to calibrate DRYMAT to the site, and so

Fig 1

CLIMATE (precipitation, solar radiation, air temperature, air vapour pressure, windspeed)
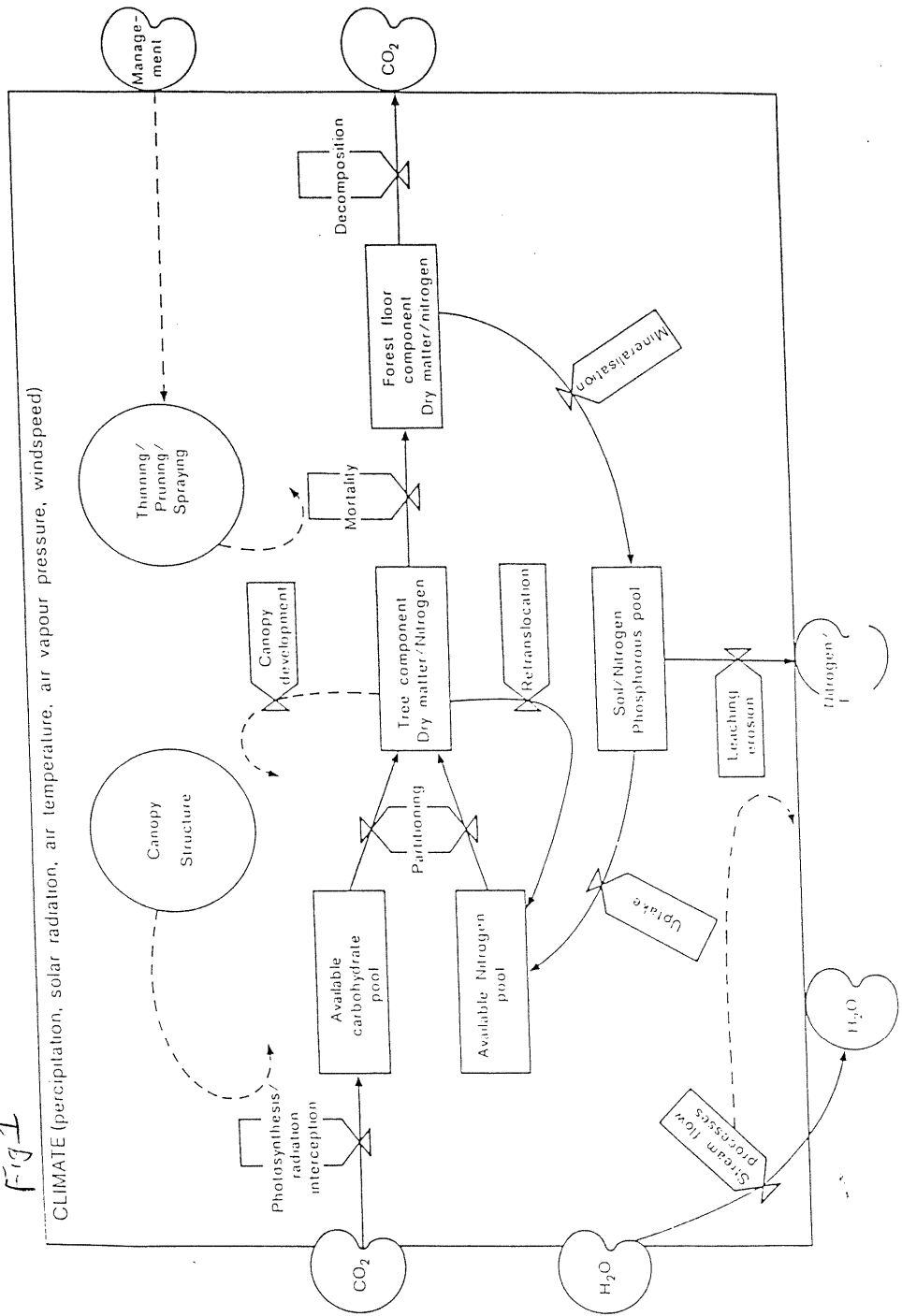
makes it possible to by-pass the difficult and error prone task of having to simulate actual photosynthesis and respiration rates from site data.

Origin of Model

The relationship between stem growth relative to that of other tree components was determined using data from several comprehensive forest biomass studies. The biomass measurements were used to calculate current annual dry matter production and partitioning of production to needles, branches, stem, and roots in relation to tree age, thinning intensity (Madgwick et al. 1977; Beets and Pollock 1987), and N fertility (Beets and Madgwick 1988, Beets and Whitehead 1995). Analysis of these datasets has shown the following regarding partitioning of production:

•Partitioning of above ground production to needles and stems is determined primarily by tree (physiological) age (Figure 2).

•Partitioning of above ground production to needles, branches, and stems does not appear to be influenced by stocking.

•Partitioning of above ground production to needles is not significantly influenced by tree nitrogen status, although partitioning to branches increases slightly at the expense of partitioning to stem, with increasing N status (Figure 3).

•Partitioning of total production to roots decreases with improved nitrogen nutrition.
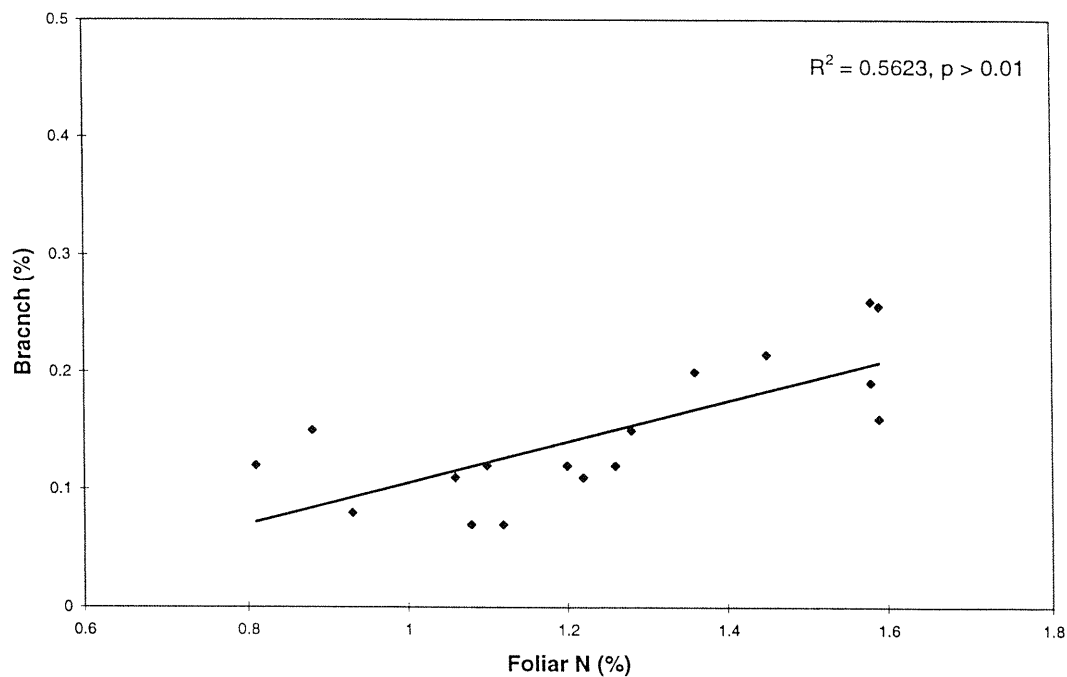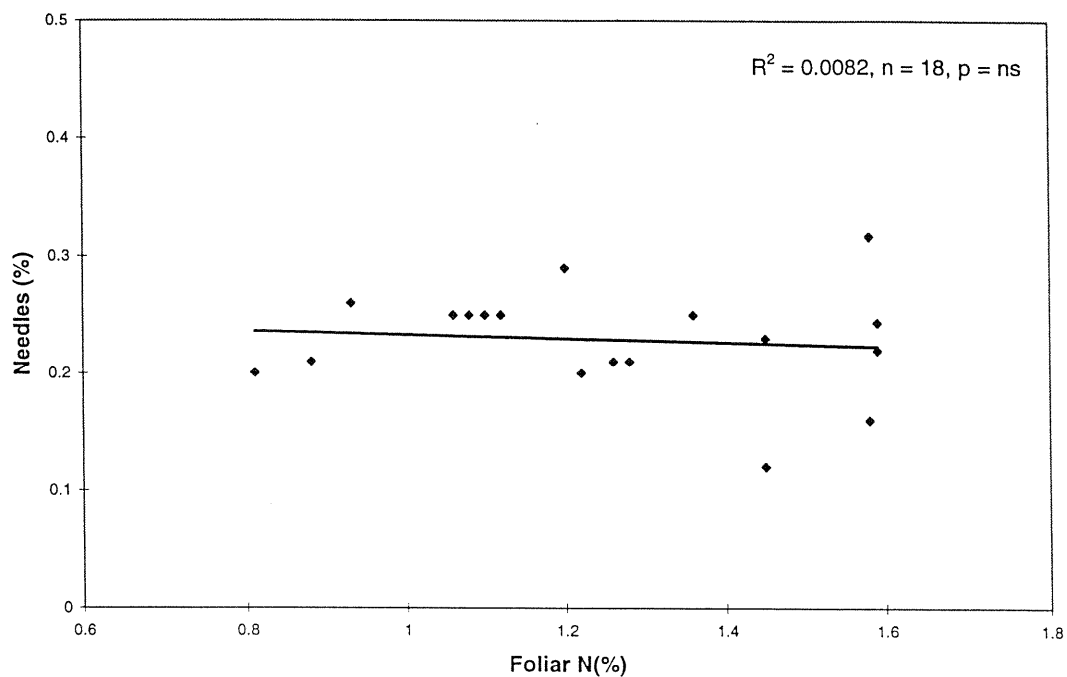
Figure 2. Proportion of current annual above ground dry matter production partitioned to needles, stem, reproductive parts, and branch at high nitrogen status sites covering a wide range in stocking, in relation to stand age
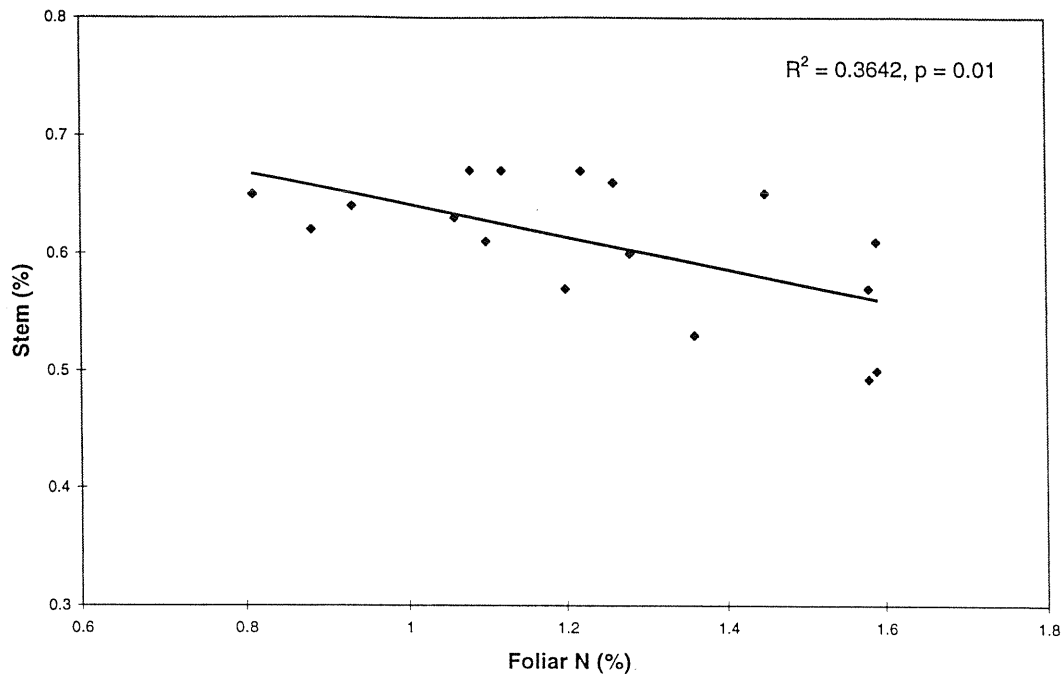
Reproduction (%) vs Stand age (years)

Branch (%) vs Stand age (years)
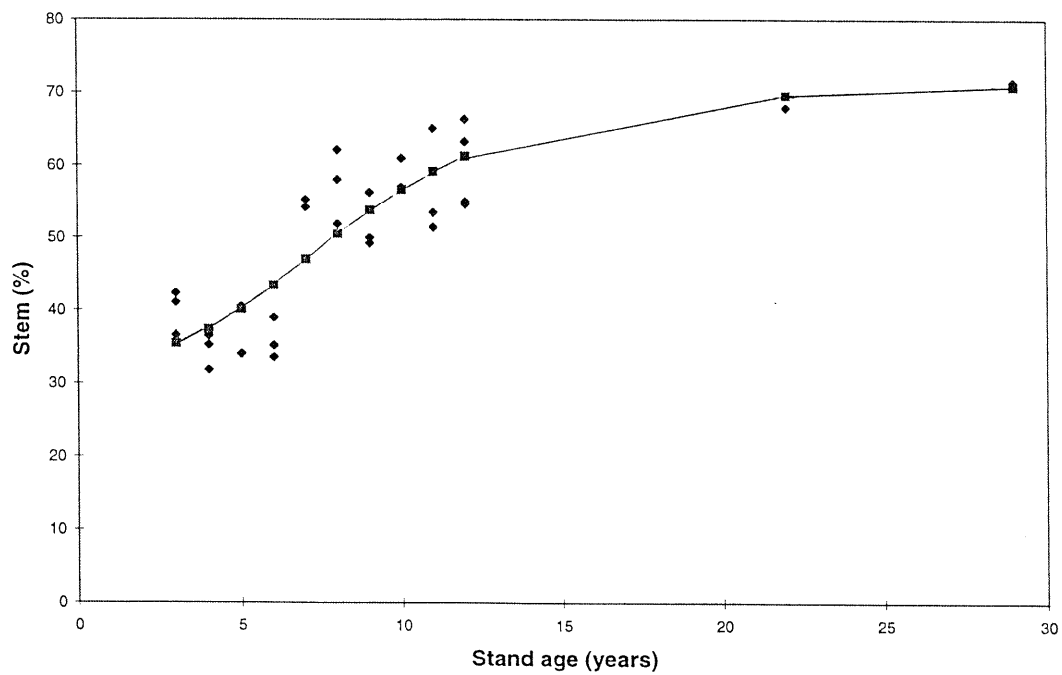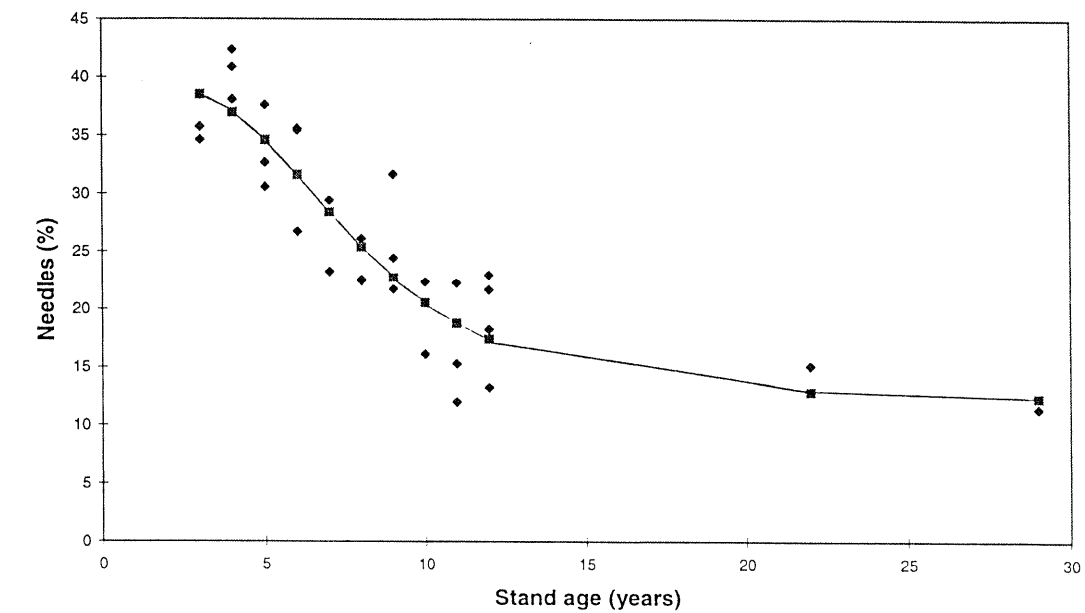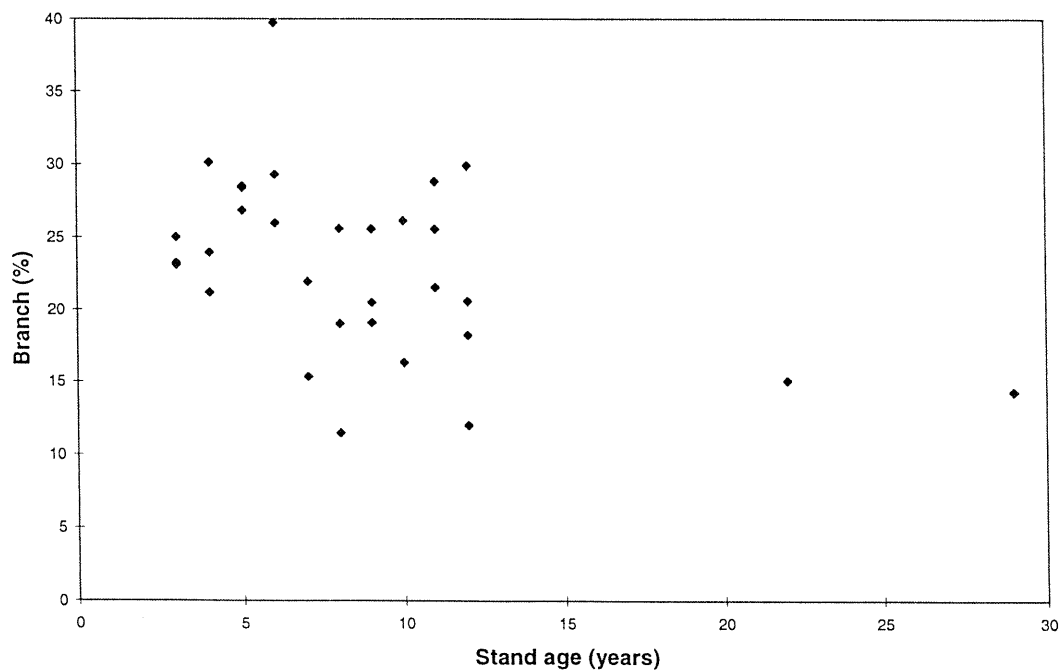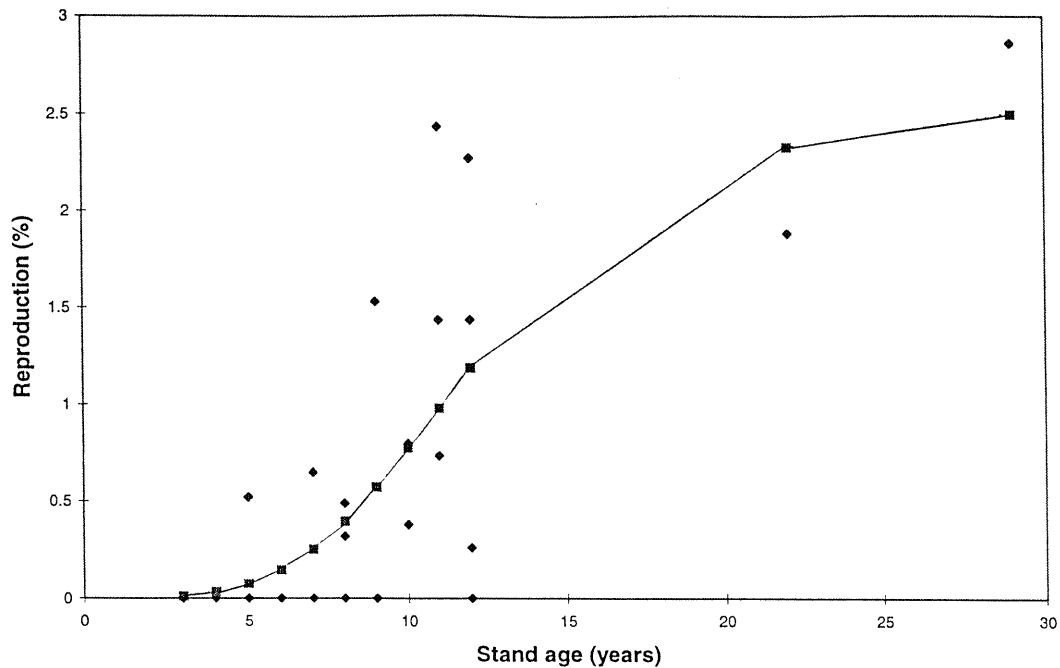
These partitioning findings were found to apply in stands where the current annual stem volume increment (CAI) in closed stands ranged between 15-52 m^3/ha/year. Consequently, the growth rate of non-stem components can be predicted, given the stem growth rate, stand age, and information on needle retention. Dry matter from living components eventually enters the forest floor, depending on needle retention parameters, and information on the frequency and intensity of pruning, thinning and harvesting. Litter compartment turnover rates determine the rate that carbon is released back to the atmosphere. Some litter eventually becomes part of the soil organic matter pool, which is not simulated at this time.

Figure 3. Proportion of current annual above ground dry matter production partitioned to needles, branch, and stem in 7-10 year old stands covering a range of N fertility, in relation to foliar nitrogen concentration

$R^2 = 0.0082$, n = 18, p = ns

$R^2 = 0.5623$, p > 0.01

The plot shows Stem (%) on the y-axis (ranging 0.3 to 0.8) versus Foliar N (%) on the x-axis (ranging 0.6 to 1.8), with a downward-sloping regression line. Annotation: $R^2 = 0.3642$, $p = 0.01$.

Model Inputs

The minimum inputs to run the DRYMAT model include:

• Initial conditions: dry weight of tree components and stand age at start of run - or use default seedling values and start at stand age 0, and stocking;

• Stand parameters (wood density region - low, medium or high; site productivity level, using actual stem volume data or, alternatively, the soil C/N ratio; needle retention (fraction of 1 year old needles retained for second year), needle loss owing to consumption, and height growth coefficients); and

• Tending/harvesting regime (timing and intensity of pruning, thinning, and harvesting operations).

These inputs allow the model to simulate the growth of a stand from time of establishment to rotation age at a particular site, through either calculating total dry matter production or simulating this from the leaf area index and its efficiency. The leaf area simulated by the model over time varies according to the needle retention parameter, to allow for the effects of defoliation by fungal diseases, and also depends on the effects of pruning to a specified height and thinning to a specified stocking at any given age. Stand dry matter content, height, basal area, and total volume inside bark are included as model outputs.

Example of possible use of model

The growth of four unthinned stands at AK287 in Woodhill Forest was simulated

using DRYMAT. The effect of low N status on branch v stem partitioning still needs to be included in DRYMAT, and the implications of not doing so are shown in table 1, where branch weight is over-estimated. However, the simulations also show that when the productivity level at stand age 20 is used as input, the Control and Lupin stands actually grew better than simulated, because N supply was initially adequate, but was apparently inadequate by age 20. A change in productivity level within a rotation has occurred. Such effects are currently not automatically simulate by DRYMAT, and time series C/N data are required to accurately predict growth.

Model inputs for nutrient cycling

More detailed data inputs (eg nutrient concentrations in particular tree components at several ages) allow the DRYMAT model to simulate nutrient fluxes (eg uptake rates in Kg/Ha/Year) and nutrient amounts (Kg/Ha) in the various tree components. Current research aims to quantify the turnover rate of nutrients in litter and slash material on the forest floor, in order to close the nutrient cycle.

Towards this end, the measured flux of phosphorus (P) from decomposing organic matter was compared with the simulated P uptake by stands in a study which exemplifies one benefit of using the DRYMAT model for predicting tree nutrient requirements (Parfitt et al. 1985). DRYMAT is currently being set up to quantify magnesium uptake and cycling rates with respect to designing improved fertilisation practices to treat stands exhibiting Upper Mid-Crown Yellowing.

Model inputs for simulating site productivity from soil data

If actual volume data from PSP's are not available, the DRYMAT model predicts the productivity level of the site from soil C/N data using a national function (figure 4). As already indicated, a soil organic matter compartment is currently not included in DRYMAT, and therefore the soil C/N ratio needs to be provided as input data. A closed nutrient cycling model is desirable in the future, to simulate variation in the C/N ratios over a rotation, and to indicate how best to manage the C/N balance through fertilisation, N-fixation, and retention of organic matter.

Figure 4: Radiata pine productivity in relation to soil C/N status

$$y = 643.15x^{-0.9003}$$
$$R^2 = 0.8582$$

CAI (m3/ha/year)

Soil adjusted C/N ratio
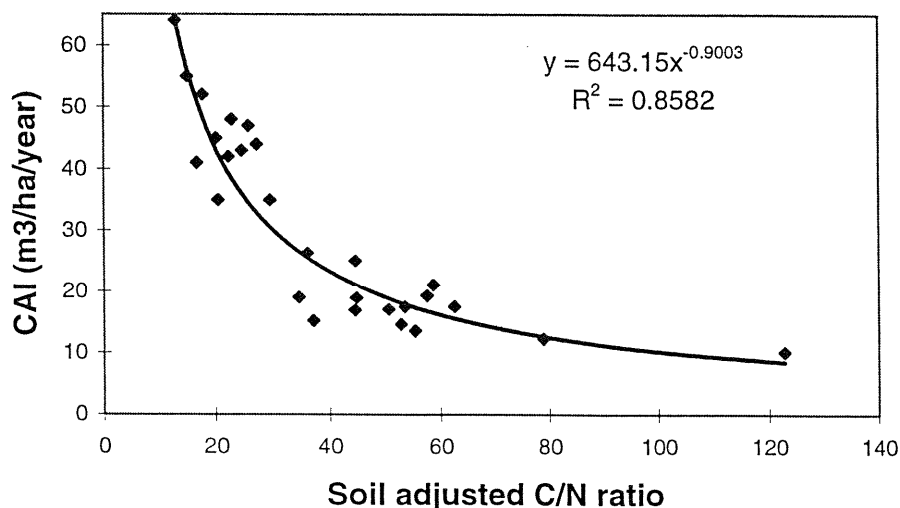
Recognised Model limitations

1) The growth rate under open grown conditions, following severe thinning or at low stockings, is not well simulated. The leaf area function used in the model does not take into account that foliage is clumped into crowns, but assumes that needles are uniformly distributed in the canopy space. This assumption becomes less valid as the stocking rate decreases. Data are currently being obtained from semi-mature open grown trees to validate intended improvements to this part of the model. Including this refinement will allow the DRYMAT model to more accurately predict growth of intensively managed stands over a wide range of stocking rates, and following heavy thinning.

2) Needle retention, litter decomposition, and forest floor nutrient turnover parameters need to be determined at more sites. The Central Volcanic Plateau parameters are currently being used because this region fairly represent national average forest litter carbon contents. However, information will need to be determined over a range of soil and climatic conditions, to provide accurate regional predictions.

3) Incorporation of forest floor and fine root dry matter and nutrient inputs into the soil needs to be examined. Fine roots represent only a small proportion of the stand total carbon content, but are an important input to the mineral soil organic matter pool, and influence the soil C/N ratio. The ability of DRYMAT to model actual changes in productivity within and between rotations, and to simulate the effectiveness of nitrogen fertilisers depends on being able to simulate temporal changes in the forest floor and soil C/N balance.

4) Limited validation data exist to test if growth partitioning on dry land sites is similar to sites with adequate water supply.

5) Forest understorey development in relation to pine crop stocking rate is not well studied, but is relevant for simulating carbon and nutrient cycling. The role of, for example, legumes in N-fixation is well known, but effects need to be incorporated into DRYMAT for the model to be responsive to vegetation management.

6) Branch mortality and dead branch decomposition/shedding rates need to be measured for a range of tree stocking rates, and parameter included in DRYMAT, by improving the green crown length submodel.

Research Directions

The value of DRYMAT as a component of decision support tools could be considerably enhanced by the following:

•Determine the potential site productivity level, as a benchmark against which actual site productivity levels can be compared. This potential value could vary spatially in relation to climate, and temporally in relation to tree improvement. It should, however, be the maximum productivity level achievable in the absence of nutrient limitations.

•Close the nutrient cycle by including a soil compartment, to allow nutrient uptake to be matched with supply. The effects of silvicultural practices such as slash retention, fertilisation, and use of legumes for N_fixation on actual productivity level could then be simulated by the model.

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Table 1. Actual (A) and predicted (P) stand weights (t/ha) of unthinned plots at AK287 in compartment 138, Woodhill Forest. Nutritional treatments include control (-L-F), lupin (+L-F), fertiliser (-L+F), and lupin plus fertiliser (+L+F).

	Age		C	L	F	LF
Needles	7	A	3.6	6.3	5.6	6.4
		P	3.1	4.8	7.2	8.5
	17	A	2.8	3.6	5.1	5.7
		P	2.4	3.5	5.1	6.2
Branch (live)	7	A	10.1	13.9	10.0	16.3
		P	8.4	12.4	17.1	18.4
	17	A	6.9	13.0	16.0	18.4
		P	17.9	17.9	18.0	18.4
Branch (dead)	7	A	1.2	1.4	1.9	2.7
		P	0.0	0.3	1.7	4.4
	17	A	8.9	12.0	16.3	20.1
		P	8.7	17.3	28.4	35.2
Stem	7	A	30.	33.	36.	35.
		P	13.	20.	30.	36.
	17	A	117.	166.	189.	216.
		P	75.	110.	162.	198.