Nutrient Dynamics of Planted Forests
Vancouver, Wa
Nov, 2012

INTER-ROTATIONAL PRODUCTIVITY
AND NUTRITION IN *Pinus radiata*
PLANTATIONS

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AUSTRALIA
RADIATA PINE PLANTATIONS

- Species native to California (~10,000ha)
- About 3.7 million ha in the southern hemisphere mainly in Chile, New Zealand and Australia
- Commercial scale planting commenced in early 20th century
- Usually grown on 25-35 year rotations
- In Australia initially planted on sites considered not suitable for other purposes, often nutritionally poor
- Significant areas now converting to second and third rotations
BROAD MANAGEMENT PRINCIPLES DEVELOPED:

• Site specific management
  • site classification system
  • Site specific information

• Plantations to be sustainable
  • can productivity be maintained across rotations?
  • range of other values

• Changes in management over time
Eucalyptus forest converted to plantation
First rotation plantation. Original timber removed by hand and pit planted
Windrowing and burning of native vegetation for first rotation pine
Radiata growing in windrow
Site preparation of pasture site for first rotation
Early deformity of radiata on site with high mineral nitrogen
Weed management critical
Sandy site, residue burnt and replanted
Maintenance of harvesting slash in establishment of second rotation
STUDY BACKGROUND

Radiata plantations are being converted to 2\textsuperscript{nd}, 3\textsuperscript{rd} or 4\textsuperscript{th} rotations and the issues are:

- Does the productive capacity (fertility) of a pine plantation site change over rotations?
- Are there changes in plantation productivity?
- Are the changes in soil related to productivity (directly or through nutritional status)?
- Can sites be categorised on the basis of risk of productive capacity change and plan management intervention?
Project Issues

• Compare soil properties between rotations
• Measure productivity between rotations
• Assess management over rotations
• Need to relate changes in productivity to changes in soil properties and/or plantation management
  [finding a change in soil properties and in productivity does not mean they are related]
• Issue of short term and long term change?
• Should we be concerned?
(Keeves 1966) productivity decline of radiata on fine sands. (O’Herir and Nambiar 2010) extended to 3R and showed improvement.
Second rotation productivity related to first rotation and age

![Graph showing the relationship between second rotation productivity and first rotation volume change over different plantation ages. The graph indicates a negative correlation, with productivity decreasing as plantation age increases.]
Radiata Pine plantation site variation

• Categorised on basis rainfall x Soil Technical Classification
  • Parent Rock Codes (Soil Parent Material)—PRC
  • PRC either in situ or transported
  • Soil profile characteristics

• High variation in properties and tree growth
Australia - Radiata Plantations

% of Total Plantation Area

Parent Rock Code

Consolidated

Un consolidated

Rainfall

>1300

1000-1300

700-1000

<700
New Zealand - Radiata Plantations

Rainfall (mm) vs. % of Total Plantation Area

Parent Rock Code

- Consolidated
- Unconsolidated

- >1600
- 1300-1600
- 1000-1300
- 700-1000
- <700
Methodology for Site Comparison

• **Direct yield comparisons.** Compare the yield of timber from compartments or blocks in different rotations.

• **Direct productivity comparisons.** Compare actual productivity of rotations (1R/2R or 1R/3R) using growth plots on the same location.

• **Productive Capacity comparisons.** Index of soil fertility. Is soil related to productivity or nutrient status?

• **Nutrient Budget analysis.** Nutrient input/output analysis.

• **Base line development.** Identification of baselines to evaluate productivity changes.
Radiata pine plantation on phosphate deficient site, Lidsdale S.F.
Soil developed from conglomerate, Lidsdale SF
Comparison of first and second rotation yield

Yield is merchantable timber expressed as mean annual volume increment (m$^3$/ha/yr)

Yield = (total volume of timber removed at final harvest (m$^3$) plus removals in thinning (m$^3$)) divided by compartment area (ha) divided by rotation length (years)
Compartment yields for first and second rotations

![Graph showing the relationship between first and second rotation volume yields.](image-url)
Comparison of first and second rotation productivity

- Productivity estimation plot based
- Plots on same location in 1R and 2R
- Re-measurement of diameters and height
- Application of same volume equations
- Productivity calculated as volume mean annual increment (m$^3$/ha/yr) at age 25 years and includes thinnings
Plot based productivity changes from first, second and third rotations.
Productivity Conclusion

• Yield and productivity declines in 2R on sites where no major change in nutrients
• 3R generally higher than 1R
• Yield and productivity of fertilized 2R sites higher. Residual effect into 3R.
• High nutrient sites 2R productivity lower but yield higher than 1R (deformity factor)
• Early growth may not reflect long term growth
Soil Analyses

- Repeat sampling of soils at same points using same analyses or paired site sampling
- Compared concentrations and quantities (kg/ha)
- Used in soil-productivity models
<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>total N</th>
<th>total P</th>
<th>Avail P</th>
<th>ex-Al</th>
<th>ex-Ca</th>
<th>ex-Mg</th>
<th>ex-K</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adjacent woodland</strong></td>
<td>4.75</td>
<td>0.55</td>
<td>117</td>
<td>1.7</td>
<td>1.3</td>
<td>1.65</td>
<td>0.61</td>
<td>0.27</td>
</tr>
<tr>
<td><strong>First Rotation 1960</strong></td>
<td>4.68</td>
<td>0.48</td>
<td>101</td>
<td>3.2</td>
<td>0.99</td>
<td>1.35</td>
<td>0.53</td>
<td>0.25</td>
</tr>
<tr>
<td><strong>Second Rotation 2012</strong></td>
<td>4.96</td>
<td>0.61</td>
<td>109</td>
<td>4.4</td>
<td>0.95</td>
<td>1.17</td>
<td>0.38</td>
<td>0.18</td>
</tr>
</tbody>
</table>
Relationship of soil factors to productivity

- Functions of productivity and soils based on 1R soils
- Applied to 2R soils to evaluate change
- Used quantity (kg/ha) to integrate soil depth data and allow assessment of losses or additions
- Lidsdale nutrient quantities (50 cm soil depth)

\[
\text{MAI (m}^3/\text{ha/yr) } = 5.093 + 0.00305*P(\text{kg/ha}) + 0.0146*\text{ex Ca(}\text{kg/ha)} + 0.107*\text{ex K (}\text{kg/ha)}
\]

\[R^2=0.763\]
\[SE=1.803\]

- Long term loss by change in soil base cations
Measured growth plot comparisons and estimated from soil changes

<table>
<thead>
<tr>
<th>% change from first rotation</th>
<th>Permian unfertilized</th>
<th>Permian fertilized</th>
<th>Devonian unfertilized</th>
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</thead>
<tbody>
<tr>
<td>1R/2R growth plot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1R/2R soil</td>
<td></td>
<td></td>
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<tr>
<td>1R/3R growth plot</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1R/3R soil</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions on Soil Analyses

- Soils change over rotations
  - P changes due to fertilizer application
  - N declines at establishment may increase
  - Cations decline
  - Others change depending on site

- Soil/productivity relationships
  - Changes in productivity can be related to soil nutrient change
  - Early productivity appears related to N and P
  - Rotation length changes largely result of cation shift
Stand Nutrition

• Nutrition assessed by foliage nutritional status
• Basis for interpretation
• Nutrients change with:
  • stand age
  • site
  • management
  • environment
Foliage Nitrogen – Age and Site

![Graph showing the relationship between Foliage Nitrogen (%), Plantation Age (years), and Site (Basalt, Shale, Sandstone 1R, Sandstone 2R, and Level)].
Foliage nutrient status of different rotations at different ages at Lidsdale

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>N (g/kg)</th>
<th>Ca (g/kg)</th>
<th>B (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1R 2R 3R</td>
<td>1R 2R 3R</td>
<td>1R 2R 3R</td>
<td>1R 2R 3R</td>
</tr>
<tr>
<td>3</td>
<td>20.1</td>
<td>19.0</td>
<td>17.7</td>
</tr>
<tr>
<td>7</td>
<td>15.5</td>
<td>14.9</td>
<td>12.9</td>
</tr>
<tr>
<td>25</td>
<td>12.5</td>
<td>12.1</td>
<td>na</td>
</tr>
</tbody>
</table>
Nitrogen uptake and requirement with age

![Graph showing nitrogen uptake and requirement with age.](image-url)
Calcium uptake and requirement with age

![Graph showing Calcium uptake and requirement with age](image)
Types I and II Fertilizer responses and Type III depletion

![Graph showing types of fertilizer responses and Type III depletion.](image-url)
CONCLUSIONS

• Changes occur in productive capacity between rotations
• Studies require multiple approaches
• Type and magnitude of change is related to site
• Early measured differences (1R/2R) not necessarily maintained through rotation
• Site differences indicate potential for classification into risk and identify risk factors for change
CONCLUSIONS (2)

• Nitrogen and phosphorus availability major factor in early stand development
• Calcium, potassium, magnesium and boron impact later even though not at apparently limiting levels
• Pool sizes based on site type major factors in long term productivity (proportional change)