Effect of Harvest Residue Management on Nutrient Cycling and Tree Growth in a Young Loblolly Pine Plantation

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Nutrient Dynamics of Planted Forests
November 27-28, 2012, Vancouver, WA
Loblolly Pine (*Pinus taeda* L.)

- Loblolly pine plantations cover more than 13 million hectares in the U.S. Southeast.
- Harvested on 20 – 35 year rotation depending on products.
- Genetic improvement and silviculture are highly advanced (50+ years of research).
- Potential productivity can exceed 35 m³ h⁻¹ year⁻¹.
- Deployment of clonal systems promises to further increase productivity.

**Graph:**
- Intensive plantations
- Traditional plantations
- Natural stands

*Source: adapted from Allen and Albaugh 2010*
Organic Matter Management

- Proactive soil management that stabilizes or increases soil organic carbon is necessary to realize the productive potential of genetically improved material.

5 – 50 Mg C ha\(^{-1}\)
80 - 200 kg N ha\(^{-1}\)

Courtesy: H. Lee Allen

Courtesy: Mike Tyree
Cross Carbon Study: Objective

- Investigate the potential to use forest logging residues incorporated into the soil during site preparation to enhance soil quality, promote short- and long-term net ecosystem productivity or carbon sequestration.

  - manipulate N availability by soil incorporation of logging residues or forest floor during site preparation
  - manipulate N demand using clones with different growth or nutrient use efficiencies
General Hypotheses

Adapted from Harrison et al. 1995
Site Location

- MeadWestvaco lands
- Berkeley County, SC
- Soils: Lynchburg/Ocilla - moderate OM, low P, SW poorly drained, high water table

- Annual precipitation: 1358 mm
- Mean temperature: January – 8 °C; July – 27 °C
Site Characteristics

- **Previous Stand:** 21 years old, 2nd rotation, harvested in May 2004
  - 518 trees ha\(^{-1}\)
  - 43 m\(^2\) ha\(^{-1}\) BA, SI\(_{25}\)=23m (75 ft)
  - ≈ 93 Mg C ha\(^{-1}\) in total biomass

- **Following harvest:**
  - ≈ 24.5 Mg ha\(^{-1}\) litter (<0.5 cm)
  - ≈ 22.0 Mg ha\(^{-1}\) wood (>0.5 cm)

- Forest floor (C:N ≈ 112) and chipping effluent (C:N ≈ 700) used as source for treatment residue.
Treatments

- Five residue treatments:
  - **Control** – no treatment
  - **Raked (R)** – \( \approx 25 \) Mg ha\(^{-1}\) Forest Floor removed
  - **Forest floor (FF)** - 25 Mg ha\(^{-1}\) FF added (High Quality, C:N\(\approx\)112)
  - **1x Logging residue (1LR)** – 25 Mg ha\(^{-1}\) LR (Low Quality, C:N\(\approx\)700)
  - **2x Logging residue (2LR)** – 50 Mg ha\(^{-1}\) LR

- 38 m x 48 m treatment plots replicated 3x
- Planted with ArborGen Clone
  - (1.8 x 4.3 m spacing-1292 trees ha\(^{-1}\))
    - AA93
    - AA32 (in C and 1LR treatments only)
- Weed control first two years
  - Arsenal, Oust
  - Broadcast or hand applied
Site Preparation

Hand raked

Raked (R) - 156 kg N ha⁻¹

Forest Floor (FF)

+ 156 kg N ha⁻¹
Site Preparation

Logging Residue (LR) +18 or 36 Kg N ha\(^{-1}\)

Double Bedded
Results

- Evaluate the influence of the residue characteristics on decomposition and nutrient release (nutrient dynamics).

- Residue effects on soil and microbial biomass carbon and nutrients

- Residue effects on tree and stand growth

- Clone x Residue
Soil Carbon - Sampling Locations

Depth (cm)

0 20 40 60 80 100

Bed
1.75 m ± 0.05 SD

Interrow
1.38 m ± 0.10 SD

Trough
0.57 m ± 0.03 SD

Zone A
Zone B
Zone C
Zone D

Original surface
Coarse Organic Fragments (COF)

Maier et al. Forest Science 2012
COF: decomposition

Residue Decomposition

\[ \frac{X_t}{X_0} = e^{-kt} \]

- Soil incorporated residues will persist for much of the rotation.

- $k = 0.17 \pm 0.01$
  - $MRT = 29.0$ years

- $k = 0.23 \pm 0.03$
  - $MRT = 20.4$ years

Maier et al. Forest Science 2012
COF: N and P Release

Nitrogen

% of initial N remaining vs Stand Age (year)

Phosphorus

% of initial P remaining vs Stand Age (year)
COF: K, Mg, and Ca release

**Potassium**

% of initial K remaining

**Magnesium**

% of initial Mg remaining

**Calcium**

% of initial Ca remaining
Soil Nutrients: Mineral Soil (<2mm)

(Bed, 0 – 60 cm)

<table>
<thead>
<tr>
<th></th>
<th>C (g kg⁻¹)</th>
<th>N (g kg⁻¹)</th>
<th>C/N</th>
<th>P (mg kg⁻¹)</th>
<th>Mg (mg kg⁻¹)</th>
<th>K (mg kg⁻¹)</th>
<th>Ca (mg kg⁻¹)</th>
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<tbody>
<tr>
<td>Control</td>
<td>37.3 ab</td>
<td>1.18 ab</td>
<td>34.9</td>
<td>26.2</td>
<td>40.8 a</td>
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<td>217 ab</td>
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<td>R</td>
<td>31.2 a</td>
<td>0.99 a</td>
<td>36.7</td>
<td>27.4</td>
<td>34.8 a</td>
<td>38.7 a</td>
<td>173 a</td>
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<tr>
<td>FF</td>
<td>46.5 bc</td>
<td>1.44 b</td>
<td>39.9</td>
<td>25.1</td>
<td>63.9 c</td>
<td>45.1 ab</td>
<td>339 d</td>
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<tr>
<td>1LR</td>
<td>48.0 c</td>
<td>1.41 b</td>
<td>54.9</td>
<td>27.7</td>
<td>51.8 b</td>
<td>49.9 b</td>
<td>264 bc</td>
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<tr>
<td>2LR</td>
<td>54.7 c</td>
<td>1.50 b</td>
<td>41.1</td>
<td>27.5</td>
<td>65.8 c</td>
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<td>307 cd</td>
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<tr>
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<td>0.09</td>
<td>7.8</td>
<td>2.5</td>
<td>2.9</td>
<td>2.6</td>
<td>18</td>
</tr>
</tbody>
</table>

- Average over years 0 – 7.

Maier et al. Forest Science 2012
## Soil Carbon: Soil Macro-Organic Matter

### Carbon OM fraction (g C kg soil\(^{-1}\))

<table>
<thead>
<tr>
<th></th>
<th>Light</th>
<th>Medium</th>
<th>Heavy</th>
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<tbody>
<tr>
<td>Control</td>
<td>3.5 a</td>
<td>7.4 ab</td>
<td>15.6 ab</td>
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<tr>
<td>R</td>
<td>2.3 a</td>
<td>4.8 a</td>
<td>12.5 a</td>
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<tr>
<td>FF</td>
<td>5.8 b</td>
<td>12.5 c</td>
<td>16.4 b</td>
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<tr>
<td>1LR</td>
<td>6.5 b</td>
<td>10.7 bc</td>
<td>20.7 c</td>
</tr>
<tr>
<td>2LR</td>
<td>9.3 c</td>
<td>14.2 c</td>
<td>22.2 c</td>
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</tbody>
</table>

- Age 7
- Macro-organic matter (150-2000 µm) – density fractions
- 60 – 80% of total soil C
- >45% OM in heavy fraction

- LR increased C in all fractions
- LR treatments are a sink for N

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Maier et al. Forest Science 2012
Residue treatments increased microbial biomass C
FF increased N mineralization
LR decreased N mineralization.
Residue Treatments: Productivity

Clone AA93 – FF

Age: 18 months

Clone AA93 – 2LR
Residue Treatments: Height

AA93

Trt x Age: p=0.004
Residue Treatments: Volume

![Graph showing stem volume over stand age for different residue treatments.](https://example.com/graph.png)

- **Stem Volume (m$^3$ ha$^{-1}$)**
  - Control
  - R
  - FF
  - 1LR
  - 2LR

- **Stand Age (years)**: 2, 3, 4, 5, 6, 7

- **Relative Volume Increment** (0.5 to 1.4)

- **trt x age**: p=0.016

Maier et al. Forest Science 2012
Belowground Biomass

- Root distribution within beds differed with treatment.
- Significance for long-term productivity?

Maier et al. Forest Science 2012
Genetics x Silviculture

**Hypotheses:**

Biomass Production

<table>
<thead>
<tr>
<th></th>
<th>AA-32</th>
<th>AA-93</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>“Wide Crown” ideotype (Low GE)</td>
<td>“Narrow Crown” ideotype (High GE)</td>
</tr>
<tr>
<td>1LR</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Genetics x Silviculture: Year 2 Growth

Year 2 Volume Growth

Seedling volume (m³ ha⁻¹)

Day of Year

Control - AA93
Control - AA32
1LR - AA93
1LR - AA32
Genetics x Silviculture: Stem biomass

- Year 7: Treatment x Clone p=0.04
- AA32 10% more stem biomass in Control than AA93
Summary

- Residue quality had a significant effect on rate of decomposition, nutrient immobilization and release:
  - LR treatments initially immobilized N and P
  - FF treatment was a source of N and P
- Residue treatments increased mineral soil C, N, Mg, K, Ca, but not P.
- Residue treatments increased microbial biomass C and N.
- Residue quality altered rates of N availability
  - high quality FF treatments increased productivity
  - low quality LR treatments inhibited productivity
  - Residue effect on growth disappeared by age 6, but...
- Raked treatment had no effect on productivity or soil C, but...
- Clone x LR treatment interaction on stem biomass accumulation.