Using the 3-PG Model to Predict and Map Hybrid Poplar Productivity in Minnesota and Wisconsin

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Overview

• Purpose of Study
• Overview of 3-PG
• Modeling Procedures
  – Data acquisition
  – Parameter values
  – Calibration
  – Validation
  – Sensitivity analysis
• Mapping
• Discussion

Mature hybrid poplar plantation in Minnesota. (photo R. Zalesny)
Purpose of Study

• Inability to predict productivity is a major obstacle for hybrid poplar deployment – stakeholders don’t like uncertainty about yields!

• Productivity for a given hybrid poplar genotype depends on **site quality** (e.g. climate and soils), and **physiological processes** governing growth

• Physiological Processes Predicting Growth (3-PG) model predicts tree growth with site-specific climate and soils data, and species-specific physiology data
  – Available free as an add-in for Microsoft Excel
  – Developed for eucalypts in Australia by Landsberg & Waring [1], and has been adapted for eucalypts and other species around the globe [2-10]
Overview of 3-PG

• So how does 3-PG work?

• “Process-based” model: uses site-specific inputs for climate and soils to estimate available pools of key resources for needed tree growth
  – Sunlight (solar radiation)
  – Soil water (precipitation, temperature, soil water holding capacity, water table depth, and texture)
  – Soil nutrients (site fertility)
Overview of 3-PG (cont.)

- Species-specific physiological parameters determine the amount and type of biomass produced from available resource pools:
  - Quantum canopy (photosynthetic) efficiency
  - Biomass partitioning (foliage, stem, roots)
  - Ratio of NPP to GPP
  - Leaf litterfall rate
  - Root turnover rate
  - The list goes on... 60 parameters in all!
Overview of 3-PG (cont.)

- Simplified mathematical structure:

\[
NPP_{\text{Total}} = \text{PAR} \times \text{CC} \times \text{LAI} \times Q_{\text{max}} \times R \times M
\]

where

- \(NPP_{\text{Total}}\) = net biomass production (\(NPP_{\text{Stem}} + NPP_{\text{Foliage}} + NPP_{\text{Roots}}\))
- \(\text{PAR}\) = photosynthetically active radiation
- \(\text{CC}\) = canopy cover (fraction of ground area)
- \(\text{LAI}\) = leaf area index (leaf area per unit ground area)
- \(Q_{\text{max}}\) = maximum quantum canopy efficiency
- \(R\) = ratio of NPP to GPP
- \(M\) = growth modifiers (available water, soil fertility, temperature, etc.)

(Adapted from Sands [11])
Modeling Procedure: Data

- Used previously published productivity data from 12 sites in Minnesota, Wisconsin, and eastern edge of the Dakotas planted in 1987 and 1988 (Netzer et al. [12])
  - *Populus deltoides* × *P. nigra* (DN) hybrids
  - Planted at 2.4m × 2.4m spacing (1,735 trees ha⁻¹)
  - Measured multiple times from age 3 to 11 years
  - Selected 8 sites for calibration (56 datapoints) and 4 sites for validation (25 datapoints)
Data (cont.)

- Summary of climate and soils data gathered for all 12 sites (red = highest, blue = lowest)

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Site</th>
<th>High Temp&lt;sup&gt;a&lt;/sup&gt; (°C; Apr-Oct)</th>
<th>Low Temp&lt;sup&gt;a&lt;/sup&gt; (°C; Apr-Oct)</th>
<th>Precipitation&lt;sup&gt;b&lt;/sup&gt; (mm; Annual)</th>
<th>Solar&lt;sup&gt;a&lt;/sup&gt; (MJ/m²/d)</th>
<th>Soil Texture&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Water Table Depth&lt;sup&gt;c&lt;/sup&gt; (cm)</th>
<th>Max Avail Water&lt;sup&gt;c&lt;/sup&gt; (mm)</th>
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<td>&gt;100</td>
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<sup>a</sup> Temperature and solar radiation data obtained from National Renewable Energy Laboratory
<sup>b</sup> Precipitation data obtained from NOAA National Climatic Data Center monthly summaries
<sup>c</sup> Soils data obtained from existing soil maps (Web Soil Survey)
Modeling Procedure: Parameters

- Of the 60 physiological parameters in the model...
  - 40 parameter values found in the literature
  - 13 parameters assigned default 3-PG values (mainly conversion factors and low-sensitivity parameters)
  - 7 parameters assigned “other” values (6 based on expert knowledge, 1 based on best-fit of model)

- For all parameter values, see article in BioEnergy Research:
Modeling Procedure: Calibration

- Manipulated unknown physiological parameter (age at full canopy; fullCanAge) along with unknown site variable (fertility rating; FR) to produce best-fit model for calibration sites

- Best-fit model selected based on lowest root mean square error (RMSE; Mg ha\(^{-1}\))

<table>
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<tr>
<th>FR</th>
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<th>RMSE</th>
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Modeling Procedure: Validation

- Used calibration settings to predict yields at the remaining 4 sites from Netzer et al. (2002)

- Model fit ($R^2=0.89$, RMSE = 8.1 Mg ha$^{-1}$) is similar as for calibration ($R^2=0.88$, RMSE = 8.8 Mg ha$^{-1}$)

$$y = 0.87x + 0.57$$

$R^2 = 0.89$

RMSE = 8.1
Validation (cont.)

• 1987 plantings
  (a) Actual biomass
  (b) Predicted biomass

• 1988 plantings
  (a) Actual biomass
  (b) Predicted biomass
Sensitivity Analysis

- Independently manipulated fullCanAge and FR to gauge model sensitivity
  - fullCanAge: 3, 4, 5, 6, 7
  - FR: 0.80, 0.85, 0.90, 0.95, 1.00

- Different sites achieved minimum RMSE at different values of fullCanAge and FR

- In reality, fullCanAge likely increases as FR decreases (hypothesized values: FR=0.85-1.00; fullCanAge=3-6)

RMSE for individual sites by (a) full canopy age, and (b) fertility rating.
Mapping

- Same physiological parameters and settings as before

- Used existing spatial layers for climate data (NARR; from NOAA) and soils data (STATSGO; from NRCS)

- Generated biomass estimates for each 32-km climate grid (Mg ha\(^{-1}\) yr\(^{-1}\) at end of 10-year rotation)

- Productivity similar to that previously reported (4.8-9.0 Mg ha\(^{-1}\) yr\(^{-1}\)) for DN34 (Zalesny et al. [13])

- Spatial pattern similar to that observed for corn grain productivity (Prince et al. [14])

Source: Ecological Applications 11: 1194-1205
• Also have recently generated county-level estimates, for ease of comparison with agricultural data

• Higher-resolution (within-county) maps may be produced with finer-scale soils data (i.e. SSURGO)
Discussion

• Overall model fit is good, but it varies by site
  – Likely due to differences between sites in actual values of fullCanAge and FR
  – Also disease was known to be an issue at some of the most over-predicted sites (FRM88, SXF87, SXF88)
• Only calibrated and validated for selected DN hybrids; other genotypes may perform differently
• Only evaluated aboveground biomass production; still needs to be calibrated & validated for height, DBH, root biomass, etc.
• Due to averaging, map should only be used at coarse (i.e. regional) scale rather than fine (i.e. landowner) scale
• Questions?

Stem canker on hybrid poplar stem. (photo R. Zalesny)
Northern States Power plant at Granite Falls, MN. (photo R. Zalesny)
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References


