Research of Poplar 107 growth models based on Green Lab theory

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Abstract

Among the methods of building virtual tree models based on the method of structure - function, GreenLab model in which the core part is Source-Sink relationship model has been widely studied. Based on the Source-Sink theory, through analysis and curve fitting between the biomass data and the structure data of new branches and leaves of Poplar 107, the growth rules about it are proposed in this paper. Three allometry models are established: new branch biomass and length, new branch biomass and diameter, new leaf biomass and area. All these organ allometry models can provide reference for computer simulation and growth analysis on Poplar 107.

Keywords: Source-Sink relationship model, Poplar 107, allometry

1.INTRODUCTION

1.1 Background

Wisdom forestry is an important part of the wisdom earth. By 2030 China will implement the three steps of target "digital forestry, wisdom forestry, ubiquitous forestry" (Feng, 2015). Quick and accurate collection, calculation and processing of forestry data and convenience sharing, presentation and service of forestry information, all these aspects are the foundation to realize wisdom forestry as well as the important support on the integration between forestry and other related industries. With the rapid development of the computer graphic technology and virtual reality technology, it has very important significance and value to simulate the morphological structure and growth process of trees using computer for both forest scene realistic simulation and forestry production management, which is also one of the main points of wisdom forestry.

Research on the growth models of virtual trees is very broad by scholars. One kind of virtual tree models can be classified as functional - structural models, which can describe the three-dimensional structure growth and change of the plant controlled by physiological process and environment (Godin et al, 2005). These models can make the connection between trees appearance morphology and growth process so that they are more close to the real world both from appearance and inner, such as LIGNUM (Sievanen et al, 2010), GreenLab (De Reffye et al, 1999), PipeTree (Kubo et al, 2005), L-PEACH (Allen et al, 2005), ECOPHYS (Rauscher et al, 1990) and so on.

GreenLab model uses double scale automata to simulate plant’s structure and adopts Source-Sink driver to simulate the functional mechanism. The source-sink theory can describe the biomass production and distribution modes. At present simulation on many plants has been implemented based on GreenLab model (Guo et al, 2009; Letort et al., 2008; Liu et al., 2010). In the source-sink model, source refers to seed and leaves while sink means all the growth organs which need biomass including rings, branches, leaves, flowers and fruit. Thus, research on the relationships between the various organs’ biomass assigned by tree and their growth features is the foundation and first important period to simulate virtual tree with GreenLab. Growth models analysis of Poplar 107 will be made from multiple sides.
1.2 Growth of trees

1) Isometry and allometry growth

Tree growth model refers to the relationship between the size and the growth of tree’s organ, which is one of the important parts of functional-structural model. The growth relationship can be represented with a power function (de Reffye et al., 1999).

\[ y = ax^b \]  

(1)

If the coefficient \( b = 1 \), it means the dependent variable \( Y \) and the independent variable \( X \) isometry growth, while \( b \neq 1 \) means the two variables is the allometry growth relationship.

2) Primary growth and secondary growth

Tree’s growth is the action outcome combined the primary growth and the secondary growth. The primary growth is also called height growth, and it is the action result of meristem tissue of root and stems. From the appearance of tree, the primary growth takes the length of trunk and branches increasing. The secondary growth, also called diameter growth, is the result of meristem tissue splitting toward the surrounding direction, such that the diameter of the tree growing as an appearance result (Guo, 2010).

2. MATERIALS AND METHODS

2.1 Materials

All the Poplar 107 data used in this paper acquired through data acquisition from a forest farm at Fugou county in Henan province of China. The forest is located in mid-latitudes with Warm temperate monsoon climate, where four seasons is clear and rainfall is abundant. The Poplar forest’s row spacing is 3m \( \times \) 4m. The detailed data of 12 selected trees are gathered among age 1 to age 6.

2.2 Methods

New part of a tree every year can reflect the characteristics of tree growth. Poplar 107 branch growth has obvious periodicity and the new part of current year can be distinguished easily from the appearance. Due to Poplar 107 is a deciduous tree, so the visible leaves are all new ones. 513 the last internodes data of branches are gathered, including internode length, diameter and biomass. Another 338 sample leaves data are gained including length, width and biomass. Statistical analysis on these new branches data is made to obtain the regression model equation. The least square method and determination coefficient are used here to judge the fitting degree of the measured values and the simulated values from current model. Bigger the value of Determination coefficient \( R^2 \) and smaller the value of residual sum of squares (RSS) is, means greater the fitting degree of the growth model.

3. RESULTS AND DISCUSSION

3.1 New branch biomass-length allometry growth model

For new branches, linear logarithmic regression analysis is made on biomass data and length data according to the age of tree respectively. Model parameters are shown in Table 1.

<table>
<thead>
<tr>
<th>Growth Age</th>
<th>Sample Size</th>
<th>( b )</th>
<th>( c )</th>
<th>( R^2 )</th>
<th>sig</th>
<th>RSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>134</td>
<td>0.683</td>
<td>2.379</td>
<td>0.941</td>
<td>0.000</td>
<td>9.772</td>
</tr>
<tr>
<td>2</td>
<td>123</td>
<td>0.687</td>
<td>2.120</td>
<td>0.953</td>
<td>0.000</td>
<td>8.756</td>
</tr>
<tr>
<td>3</td>
<td>51</td>
<td>0.563</td>
<td>2.263</td>
<td>0.717</td>
<td>0.000</td>
<td>15.954</td>
</tr>
<tr>
<td>4</td>
<td>65</td>
<td>0.638</td>
<td>2.405</td>
<td>0.874</td>
<td>0.000</td>
<td>11.405</td>
</tr>
<tr>
<td>5</td>
<td>140</td>
<td>0.588</td>
<td>2.274</td>
<td>0.825</td>
<td>0.000</td>
<td>22.535</td>
</tr>
</tbody>
</table>
It can be seen from the above Table 1 that the new branches have obvious correlation between their biomass data and length data with the determination coefficient more than 0.71. For all the 5 models, every slope value b is not equal to 1, and at 95% confidence level every confidence interval is: [0.667, 0.723], [0.660, 0.715], [0.461, 0.664], [0.577, 0.699] and [0.543, 0.634]. So, the result can be obtained that the relationship between new branch biomass and length of Poplar 107 is conform to the laws of allometry model. The distribution diagram of 2-year-old and 4-year-old variables is shown in Figure 1.

Figure 1. Allometric relationship between new branches biomass and length

3.2 New branch biomass-diameter allometry growth model

Change of internode diameter of each branch embodies the secondary growth of tree. For new branches, linear logarithmic regression analysis is made on biomass data and diameter data according to the age of tree respectively. Model parameters are shown in Table 2.

It can be seen from the above table that the new branches have obvious correlation between their biomass data and diameter data with the determination coefficient more than 0.84. For all the 5 models, every slope value b is not equal to 1, and at 95% confidence level every confidence interval is:[0.242, 0.260], [0.230, 0.258], [0.194, 0.290], [0.310, 0.370] and [0.236, 0.273]. So, the result can be obtained that the relationship between new branch biomass and diameter of Poplar 107 is conform to the laws of allometry model. The distribution diagram of 2-year-old and 4-year-old variables is shown in Figure 2.
3.3 New leaf biomass-area allometry growth model

Because Poplar 107 leaf is not a regular graph, it’s area can’t be measured easily. Leaf externalrectangle is proposed here to discuss, showed as Figure 3. The rectangle combined by leaf length and leaf width is the leaf external rectangle.

![Leaf externalrectangle](image)

Some sample leaves are chosen to measure their areas by professional tool. Then a correlation analysis is take between leaf area and its external rectangle area, and as a result the Pearson correlation coefficient is equal to 0.997, which means significant correlation between them. Linear logarithmic regression analysis is made on leaf area data and its external rectangle area data. Model parameters are shown in Table 3.

<table>
<thead>
<tr>
<th>Y</th>
<th>X</th>
<th>B</th>
<th>R²</th>
<th>sig</th>
<th>RSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf area</td>
<td>Leaf external rectangle area</td>
<td>0.610</td>
<td>0.999</td>
<td>0.000</td>
<td>83.268</td>
</tr>
</tbody>
</table>

The slope value b is 0.61, and at 95% confidence level confidence interval is[0.611, 0.627]. After F test and t test, the significant values are all equal to 0.000, thus the fitting linear equation between leaf area and its external rectangle area is

\[ y = 0.61x \]  (2)
For the other sampled 338 leaves, linear and nonlinear logarithmic regression analysis are made on biomass ($W_L$) data and external rectangle area ($S$) data respectively. Model parameters are shown in Table 4.

<table>
<thead>
<tr>
<th>Model</th>
<th>$a$</th>
<th>$b$</th>
<th>$R^2$</th>
<th>sig</th>
<th>RSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S = aW_L + b$</td>
<td>15.868</td>
<td>-11.672</td>
<td>0.961</td>
<td>0.000</td>
<td>19905.944</td>
</tr>
<tr>
<td>$S = a(W_L)^b$</td>
<td>787.608</td>
<td>1.350</td>
<td>0.991</td>
<td>0.000</td>
<td>3.935</td>
</tr>
</tbody>
</table>

By comparison between the two models parameters listed in Table 4, it can be seen that the $R^2$ value 0.991 of the linear model is greater than that of the nonlinear model 0.961, and the sum of squared residuals (RSS) of the second model is smaller than that of the first one. So the power function model owns the better fitting degree. Because the coefficient of the power function is not equal to 1, a result can be gained that the relationship of leaf biomass and leaf external rectangle area meet the rules of allometry, shown as Figure 4.

![Figure 4. Allometric relationship between leaf biomass and Leaf external rectangle](image)

Thus, the leaf biomass allometry model has the equation as

$$S = 787.608 \times (W_L)^{1.350}$$  (3)

The linear relationship between leaf area and its external rectangle area has been discussed above, thus it can be reasoned out that the relationship between leaf biomass ($WL$) and leaf area ($SL$) is also meet the rules of allometry

$$S_L = 480.441 \times (W_L)^{1.350}$$  (4)

4. CONCLUSION

GreenLab is a popular functional - structural model and its theory reflected plant biomass distribution and growth process. In this paper, 3 allometry models of Poplar 107 are preferred based on the source-sink theory of GreenLab by analysing the relationship and taking curve fitting between new branch a leaf biomass and their structural growth data. The 3 models are: new branch biomass-length allometry growth model, new branch biomass-diameter allometry growth model and new leaf biomass-area allometry growth model. The results of this paper can provide reference value for computer simulation and growth analysis on Poplar 107.
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REFERENCES


